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Original Research Article

A case study on toughness of material by varying different process parameters as well as sampling, through Charpy V Notch test

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ABSTRACT

In any research of failure analysis, the impact test is most vital testing. Metals with a sharp stress raiser (notch) can undergo a notch-bar impact test, which gives information about the failure mode under high velocity loading circumstances that causes abrupt fracture. Toughness, or the area under the stress-strain curve, is typically correlated with the energy absorbed at fracture. Because of their limited toughness, brittle materials have a narrow area under the stress-strain curve, which means that little energy is absorbed during impact failure. The area under the curve, absorbed energy, and toughness all rise in tandem with the materials' ductility, or capacity for plastic deformation. The fracture surfaces of specimens exhibit similar features. The metals have a crystalline look and reasonably smooth fracture surfaces for low energy impact failures, which indicates brittle behavior. Charpy and Izod standardized tests are widely used to assess the impact energy. In the present work, a case study on toughness property has been done by play with parameters like specimen size, placed position, sample preparation, testing procedure, heat treatment, temperature, metallurgical, mechanical and chemical behavior to achieve the desired impact value by choosing appropriate sample as well as process parameters. Any one of misbalances the chances of wrong reading. Analytical models on sample and process are used to define this case study. Metallurgical sciences are very powerful zone to study any material characteristics. In this work, it is observed that the analytical report or case study has shown reasonably good results on the issue.

1. Introduction

The impact test analyzes how much energy a material absorbs during fracture. This absorbed energy serves as a gauge for the toughness of a material and may be used to investigate the temperature-dependent brittle-ductile transition. The purpose of it [1] is to figure out if the substance is brittle or ductile. Engineers test the ability of a material to withstand impact to predict its behavior under actual conditions. Many materials [2] fail suddenly under impact, at flaws/cracks or notches. Impact resistance is one of the most important properties for a part designer to consider, and without question, the most difficult to quantify. In many applications, a part's ability to withstand impacts is a crucial indicator of its longevity. Nowadays, it has to do with the confusing issue of product responsibility and safety. An impact blows from a weighted pendulum hammer that is discharged from a place at a set height h applies the load. When the pendulum, which has a knife edge, is released, it hits and fractures the specimen at the notch where it is placed at the base. The pendulum continues its swing, rising a maximum height h' which should be lower than h naturally. The energy absorbed at fracture E can be obtained by simply calculating the difference in potential energy of the pendulum before and after the test such as, $E = mg(h–h')$.

The main objective of this work is to study the relation of toughness property with strength of material and how it depends on process as well as product's parameter under different cases to get desired value at the proper state of testing.

Figure 1: Image of toughness under stress-strain curve.

2. Physical, chemical and metallurgical study of material based on process and parameter

This section describes concisely the detail methodology/procedures employed Provide sufficient detail so as to remove any possible ambiguities with respect to design, treatments, measurements, analysis, etc.

1. Width

Specimen width was prepared by follow the std. sub size as per spec. The std. sub sizes are mentioned at below fig. If specimen width increases gradually then impact value also increase gradually for same material. Alternatively, if specimen width decreases gradually then impact value also decrease gradually for same material, at constant other all factors or parameters.

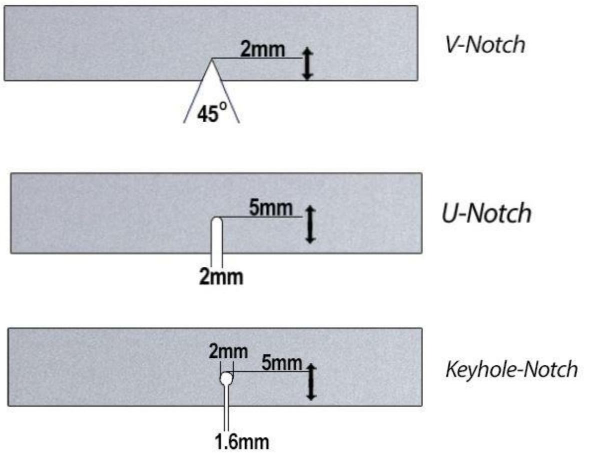


Figure 2: .Image of specimens of different types of impact test.

2. Angle

Value of V notch angle is standard, which is 45-degree. If notch angle increases its mean during sample preparation at notch area volume of material will be decreases. Less volume of material cannot able to absorb more energy. So during sample preparation if angle value increase out of tolerance then impact value will be less for same material, at constant other all factors or parameters. Alternatively, if angle value decrease out of tolerance then impact value will be increase for same material, at constant other all factors or parameters. During sample preparation must take care at angle measurement.

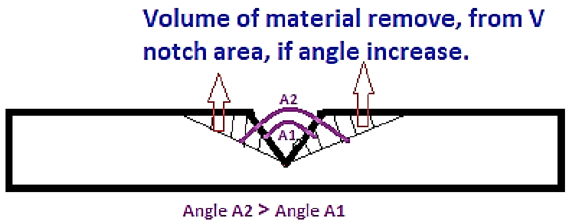


Figure 3: Image of V notch angle variation effect on toughness.

3. Notch depth

Another hand same issue will happen, if notch depth increases its mean during sample preparation at notch area volume of material will be decreases. Less volume of material cannot able to absorb more energy. So during sample preparation if depth value increase out of tolerance then impact value will be less for same material, at constant other all factors or parameters. Alternatively, if depth value decrease out of tolerance then impact value will be increase for same material, at constant other all factors or parameters. During [3] sample preparation must take care at notch depth measurement, it must be 2 mm.

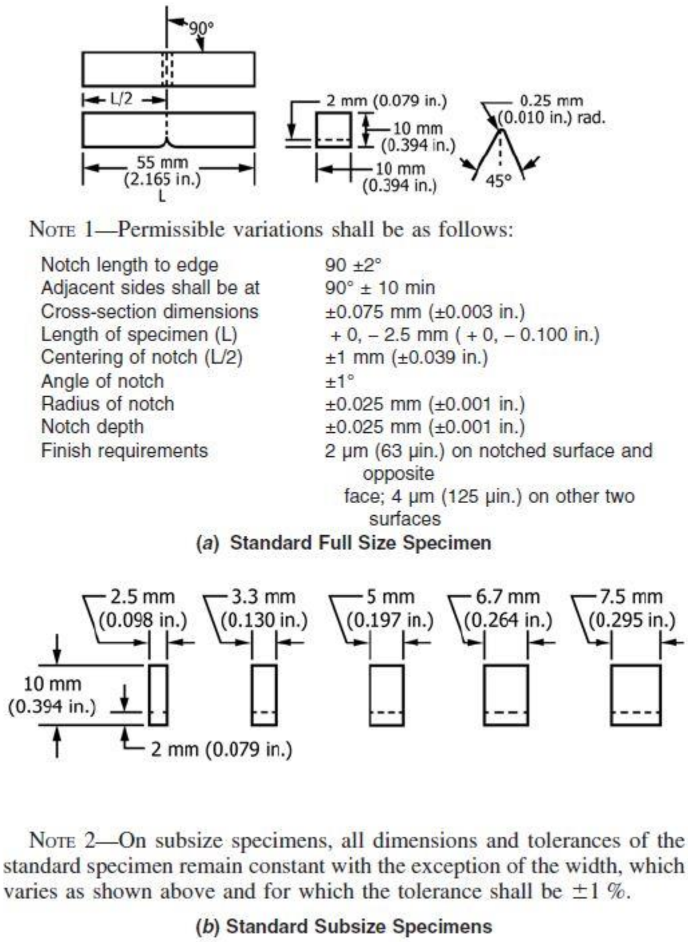


Figure 4: (a) Image of standard sample and sub size sample.

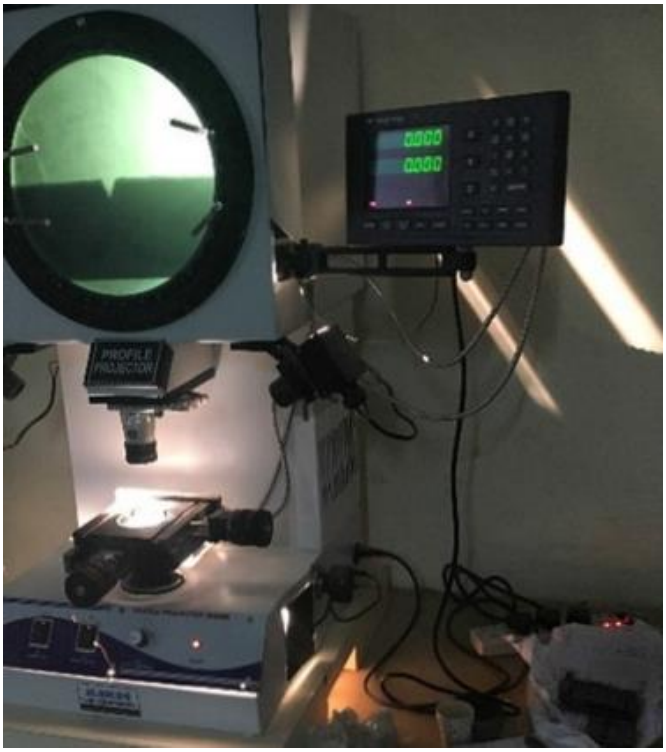


Figure 4: (b) Profile Projector to measure sample dimension.

4. Testing temperature

For charpy impact test testing temperature followed as per std. spec. or application based of different grades of material. As per reference std. spec. ASTM A334 and A336 generally followed. When any metal used under high temperature environment then at lab the testing temperature will high. Same when any metal used under low temperature environment then at lab the testing temperature will low. If testing temperature increases gradually then impact value also increase gradually for same material. Alternatively, if the testing temperature decreases gradually then impact value also decrease gradually for same material, at constant other all factors or parameters. At cryogenic condition due to sudden temperature drop, atoms stuck strongly that's why material behaves as brittle fracture and reduce the capability of energy absorption. Alternatively, at high temperature due to sudden temperature gain, atoms move that's why material behaves as ductile fracture and induce the capability of energy. Test can be conduct under highly negative as well as highly positive temperature.

5. Yield and ultimate stress

Tensile and hardness tests are generally conduct on material, impact test conduct rarely. Yield stress, ultimate tensile stress, hardness and impact property are related to each other.

When the yield stress and ultimate tensile stress values are extremely high, the material is stronger. High properties are displayed by hard materials. Such material is not able to withstand an abrupt drop in load. Because of the low energy absorption capabilities, the impact value is low. On the other hand, low yield and ultimately tensile strained materials will exhibit the reverse effect.

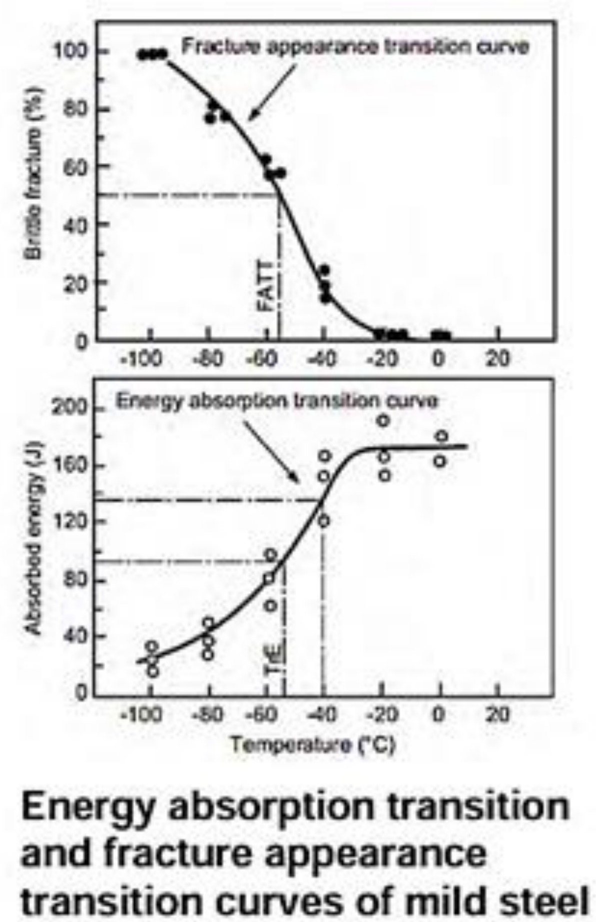
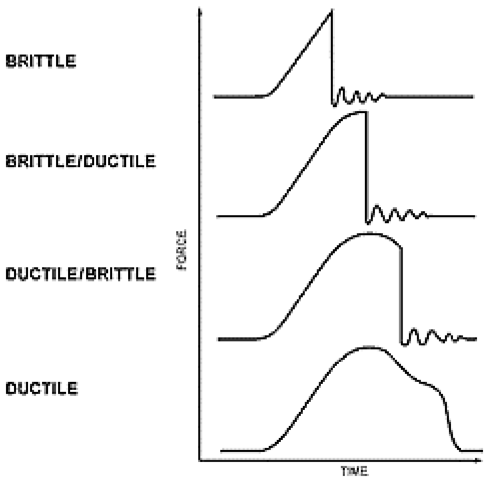


Figure 5: Image of brittle-temperature curve and energy-temperature curve.

6. Elongation

A material with a high percentage of elongation can absorb higher impact value during a tensile test. By elongating itself and dispersing the energy evenly throughout its body, the sample absorbs more energy. Stress concentration disperses as a homogeneous wave flow during elongation. The plasticity characteristic of metal provides good toughness.



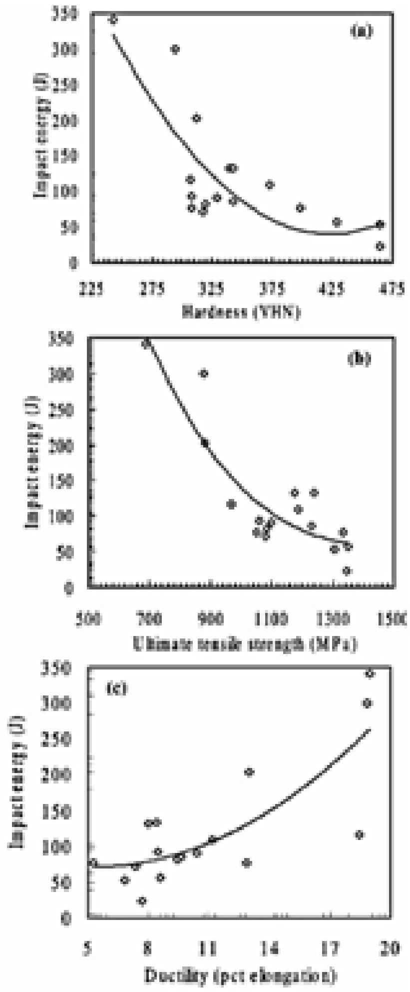


Figure 6: Image of impact energy vs. mechanical property [4-5].

7. Grain size

If microstructure of material with very fine grain size [6-9], then its provide high strength and absorb less impact energy than coarse grain. Material with coarse grain can absorb more impact energy than fine grain. Stress full microstructure or stressed grain behaves as brittle fracture during V notch test. Grain flow, distribution of phases, uniformness effect on toughness.

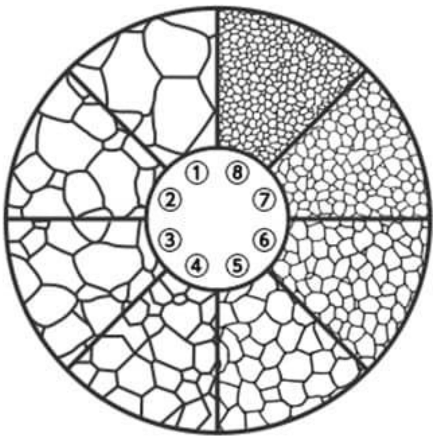


Figure 7: Image of grain chart.

8. Microstructure

Pearlite is hard and brittle, whereas ferrite is ductile and soft [10]. The fraction of pearlite increases along with the bulk strength as the total carbon content rises. The toughest yet most brittle microstructure is martensite. Pearlite [11] has strength but lacks toughness. Bainite is tougher than pearlite but not as hard as martensite, giving it a suitable strength-ductility combination.Martensitic [12] structure offers less impact energy value than bainite, pearlite and ferrite. The "face-centered-cubic" (fcc) crystal structure of austenitic stainless steels [13–14] is identical to that of pure iron above the A3 temperature of 910 degrees Celsius. This structure is maintained by pure iron until it reaches the A4 temperature of 1390 degrees Celsius, at which point it returns to the BCC structure. In general, BCC metals are more brittle. Their dislocation lattice friction stresses are larger than those of FCC metals, which is the primary cause.Martensite [15-16] has bcc structure at low carbon concentrations or a body cantered tetragonal (BCT) structure at high carbon concentrations.

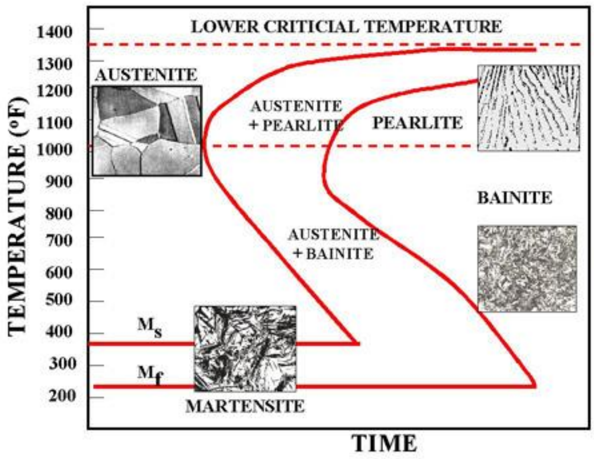


Figure 8: Image of TTT diagram [17].

9. DBTT

The ductile-brittle transition temperature (DBTT) is the temperature at which a material is brittle and above which it is ductile [18–20].(NDT). The nil ductility temperature [21-23] is not precise but varies according to prior mechanical and heat treatment and the nature and amounts of impurity elements. Many cases have occurred through history as like tetanic accident, where catastrophic failures have occurred as a result of brittle fracture. Different parts like frame of marine vehicle, turbine blade [24], high speed tool, cryogenic vessel etc. most probably go through charpy V notch test, to check longevity and sustainability of component.

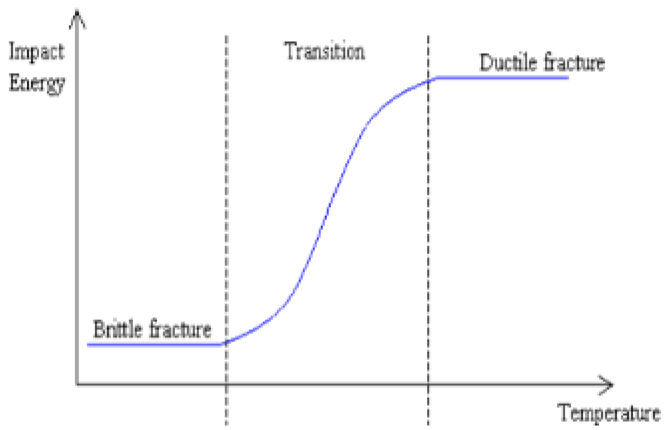


Figure 9: Image of DBTT.

10. Chemical composition [25-30]

The toughness property is depended on presence of chemical element also. Carbon, manganese, chromium, moly, vanadium, titanium, alloying elements are liable for toughness property.

Carbon (C): the most crucial component of steel. It increases hardness, tensile strength, and resistance to abrasion and wear. It reduces toughness, machinability, and ductility.

Chromium (CR): increases resistance to wear and abrasion, corrosion, scaling at high temperatures, hardness, toughness, hardenability, and tensile strength.

Manganese (MN): It improves wear resistance, hardness, hardenability, and tensile strength. It lessens the propensity for distortion and scaling. In carburizing, it accelerates the rate of carbon penetration.

Molybdenum (MO): enhances creep resistance, strength at high temperatures, and hardness, toughness, hardenability, and strength.

Vanadium (V): improves hardness, strength, resilience to shock, and resistance to wear. Higher quenching temperatures are made possible by its ability to slow grain development.

Phosphorus (P): enhances machinability and increases hardness and strength. But it gives steel a noticeable cold-shortness or brittleness.

Sulphur (S): enhances machinability in free-cutting steels, but it causes brittleness at red heat if there is insufficient manganese. It reduces ductility and impact toughness.

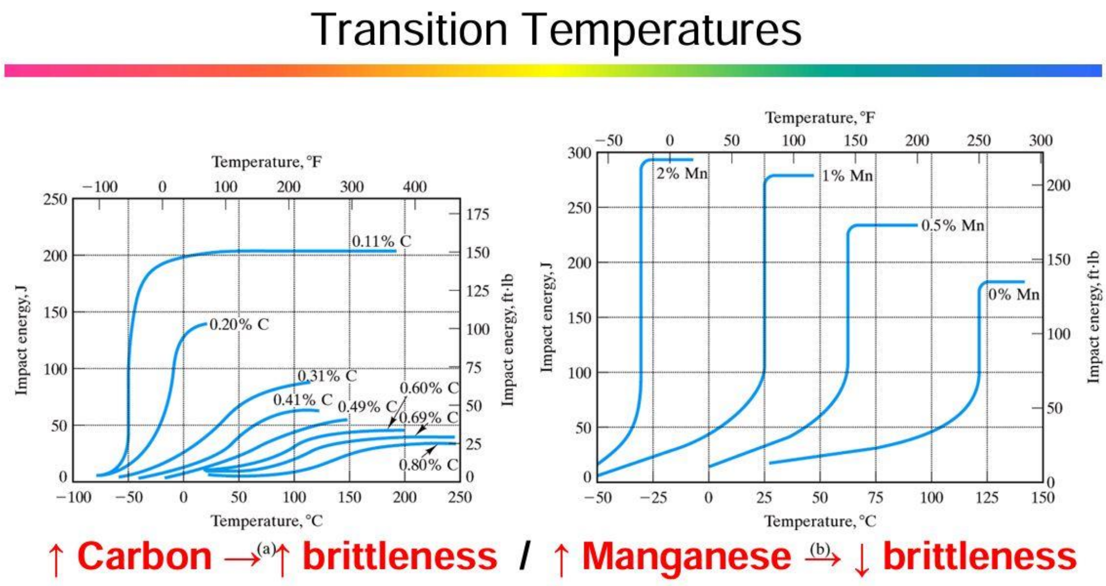


Figure 10: Image of DBTT curve shifting based on chemical composition.

11. BCC/FCC or HCP

Typically, BCC metals are more brittle. They have larger dislocation lattice friction stresses than FCC metals, which is the primary cause [31]. In contrast to FCC [32] metals, dislocations in BCC lattices migrate less easily, resulting in reduced plasticity. Metals with a bcc structure are less malleable than those that are packed closely together. During deformation, the atoms' planes have to slide past one another.The high atomic density planes and high atomic density directions, in which dislocations travel, combine to form a slip [33] system. Above the A3 temperature of 910 degrees Celsius, austenitic stainless [34] steels have the same "face-centered-cubic" (fcc) crystal structure as pure iron. This structure is maintained by pure iron until it reaches the A4 temperature of 1390 degrees Celsius, at which point it returns to the BCC structure.

2.1 Heat treatment

The strength and hardness of a material are greatly influenced by heat treatment[35-38]. The annealed product is tougher to normalize. Normalized product has fine grain structure, whereas annealed product has coarse grain structure[39-41]. Toughness is low in the stress-relieved sample because although the stress in the grain was reduced during the stress-relief procedure, no such grain was improved. Compared to such kinds of heat treatment processes, quenched products offer less toughness. Tempering is such heat treatment which offer quite toughness property in quenched sample.

3. Conclusions and discussion

This section describes clearly the observations made and their concise interpretation. The conclusions summarize the most important review and comments from this case study,for any practical work at testing laboratory as well as at industry. Any material's toughness can be attributed to its physical, chemical, or metallurgical characteristics. Toughness is dependent on mechanical properties, sample sampling, and sample environmental conditions from a physical standpoint. Chemical composition refers to the existence of several chemical elements that provide the right strength for a substance. Every single component is significant on its own in this case. We can control the parameter of heat treatment to obtain the desired toughness and strength. The scientific structure of a material and heat treatment are intrinsically linked to metallurgical facts. From this paper the valuable output and analytical review is also affected for Izod test, U notch test, keyhole notch test. Because sampling types, sub size and sampling process fall effect on property. Impact test is mandatory for aerospace, defense, oil and gas, marine, any precision equipment maker etc. sectors. Toughness measurement by impact is not a very regular applied process. In future more research on this topic can open up the new horizon of failure science and advance design analysis.

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Authors' contributions

I have read and approved the final manuscript. Author 1: Review survey, Case study, Methodology, Investigation, Formal analysis. Supervision.

Conflicts of interest

The author declares no conflict of interest.

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Data availability

No new data were created.

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